US006432330B1

(12) **United States Patent**
Hanabe et al.

(10) **Patent No.: US 6,432,330 B1**
(45) **Date of Patent: Aug. 13, 2002**

(54) **JET SYSTEM FOR SPHERICAL SHAPE DEVICES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/683,775**

(22) Filed: **Feb. 13, 2002**

Related U.S. Application Data

(60) Provisional application No. 60/279,484, filed on Mar. 28, 2001.

(51) **Int. Cl.**[7] **B29B 9/10**

(52) **U.S. Cl.** **264/9**; 264/13; 425/6; 75/335; 75/340

(58) **Field of Search** 264/5, 7, 9, 13; 425/6; 75/330, 335, 340

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,951,790 A * 3/1934 Curran 264/13
4,986,941 A * 1/1991 Hendrix et al. 264/13

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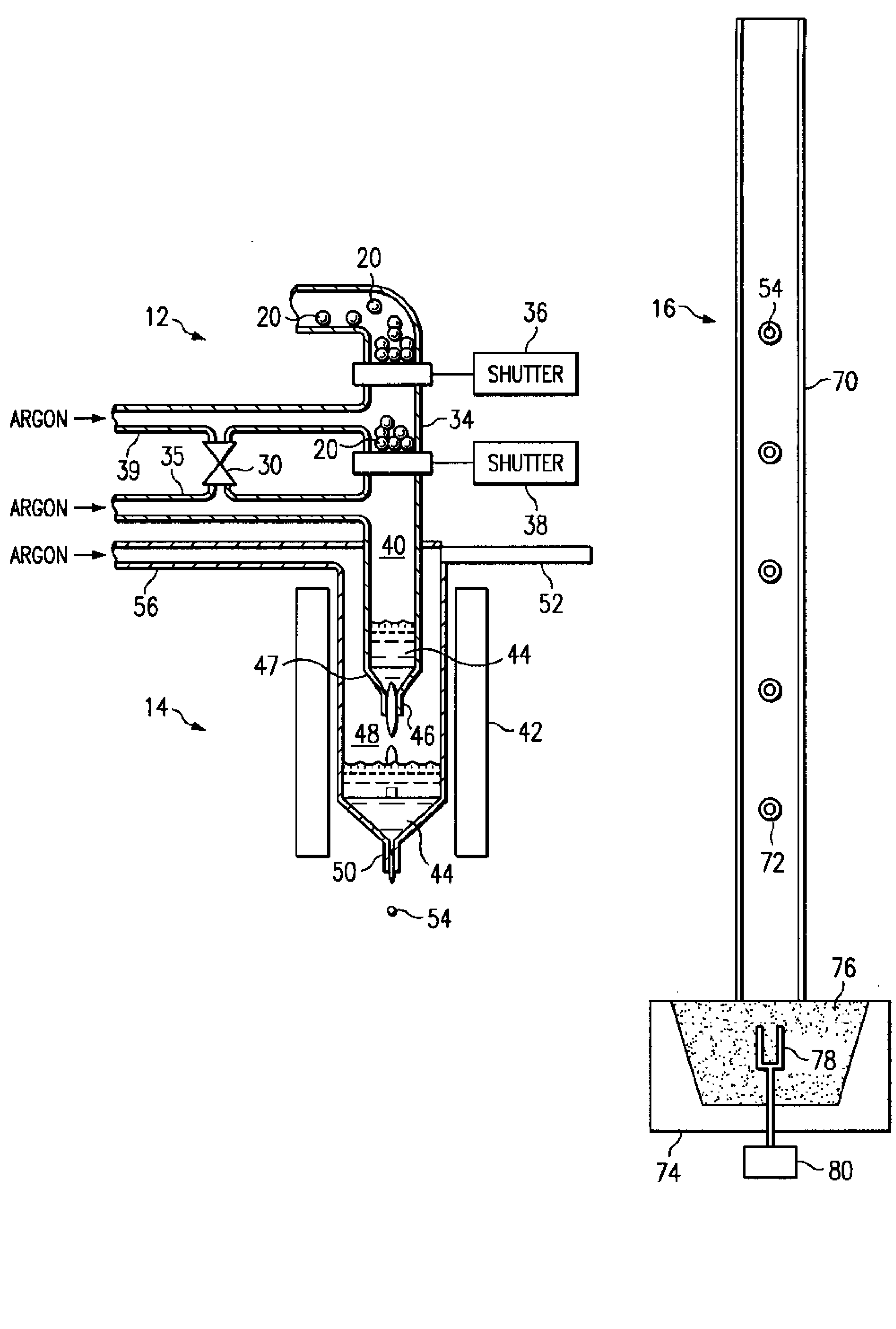
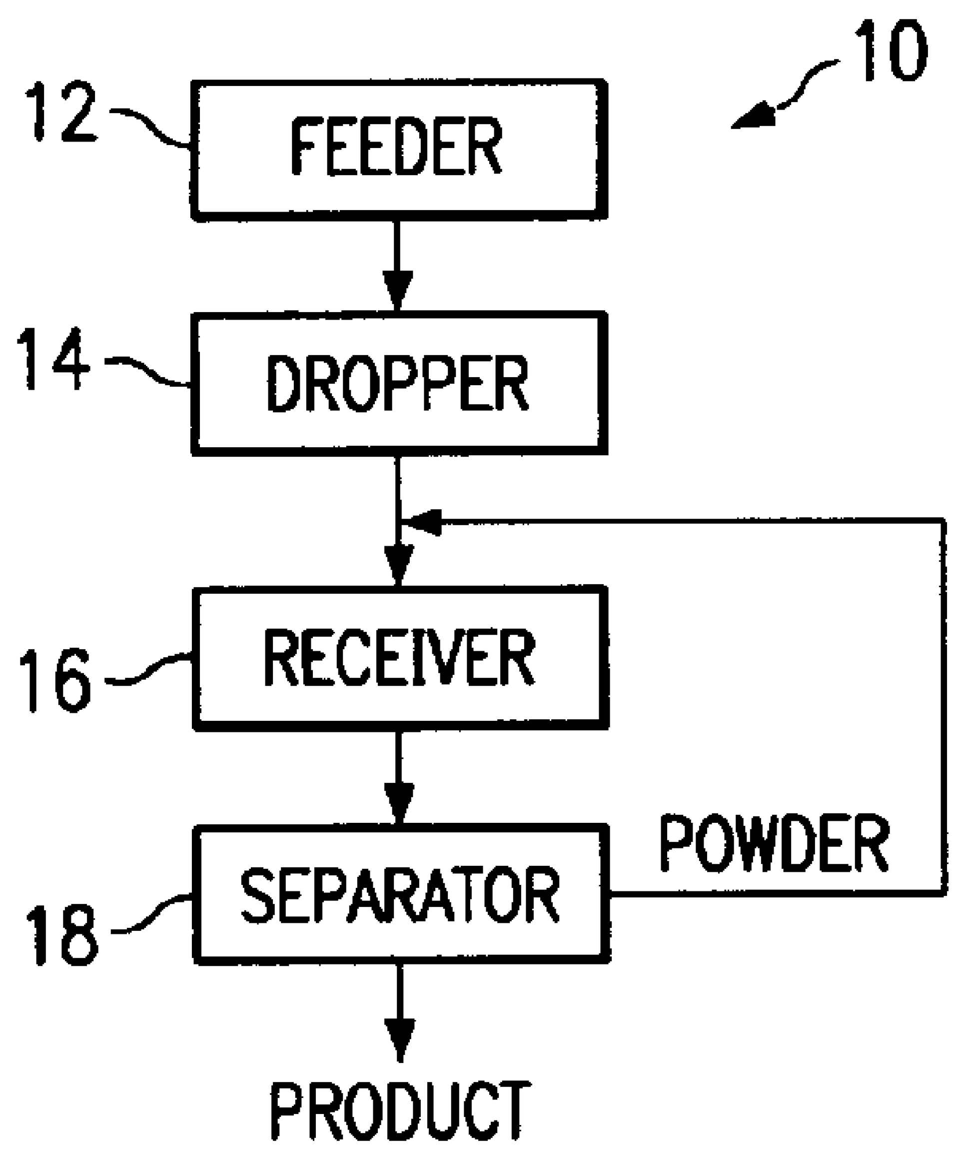
(57) **ABSTRACT**

A system and method for making very small (e.g., 1 millimeter diameter) spherical shaped devices is disclosed. The system includes a supply system for providing predetermined amounts of raw material into a chamber, which is used for melting the raw material. The melted raw material is then provided to a dropper for measuring predetermined amounts of the melted raw material (droplets) and releasing the droplets into a drop tube, where they are cooled and solidified into spherical shaped silicon devices. The system includes a container of silicon powder in which the solidified spherical shaped devices are received from the drop tube, the container including a stirring mechanism for agitating the silicon powder. The system also includes a separating device for separating the powder from the solidified spherical shaped devices after the devices have been received into the container.

20 Claims, 3 Drawing Sheets

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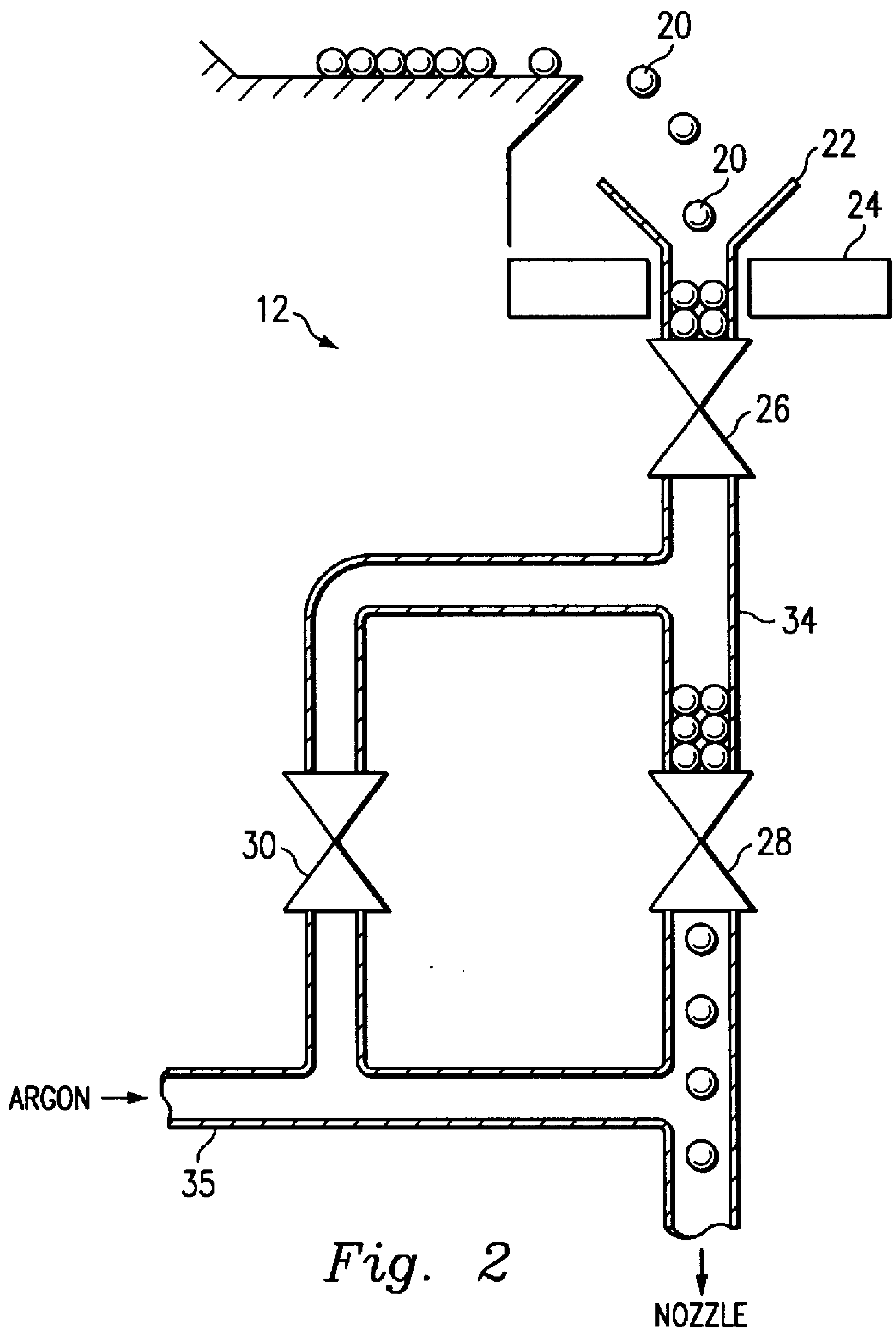
12
FEEDER
14
DROPPER
16
RECEIVER
18
SEPARATOR
POWDER
PRODUCT

Fig. 1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ARGON
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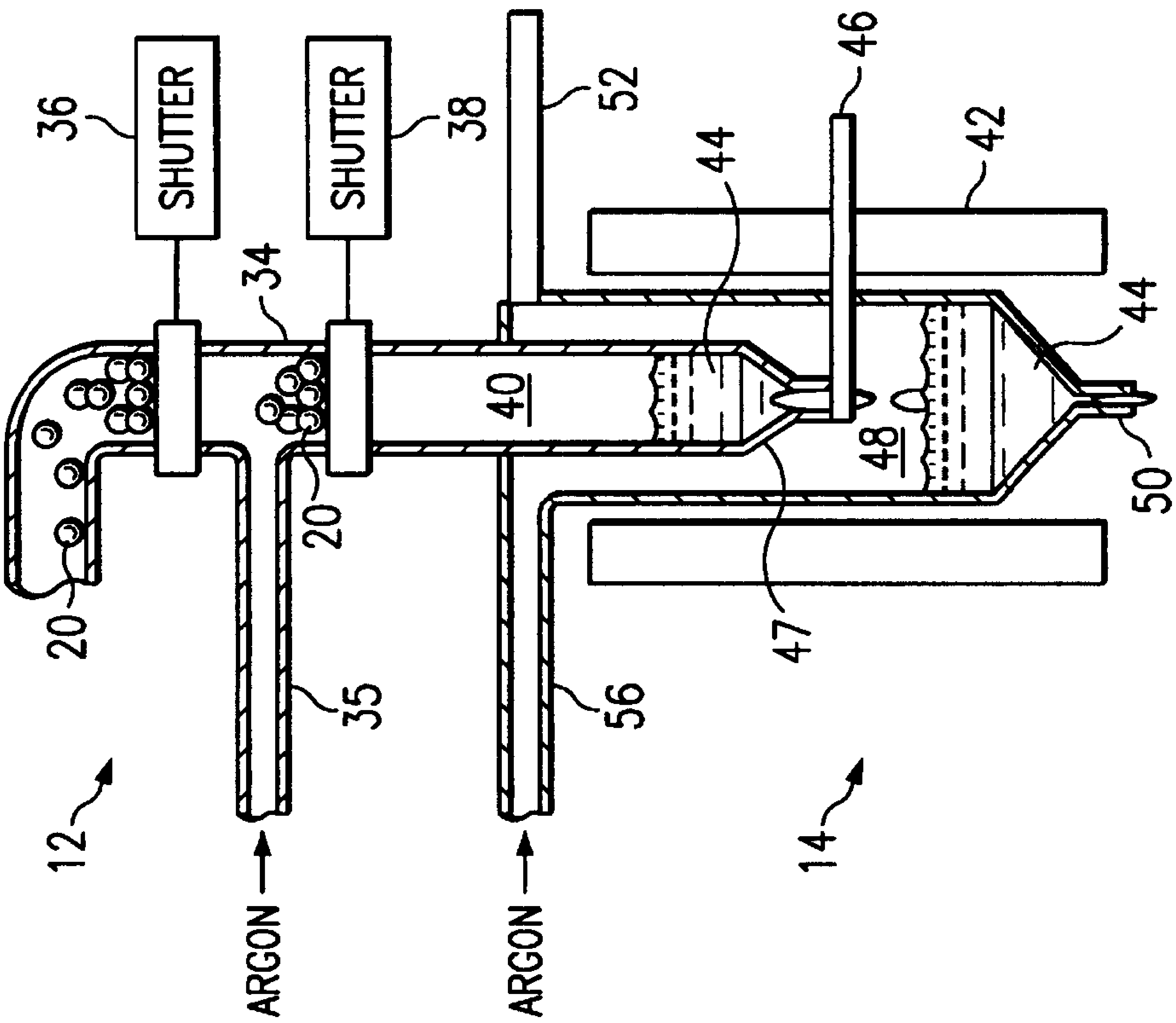
NOZZLE

Fig. 2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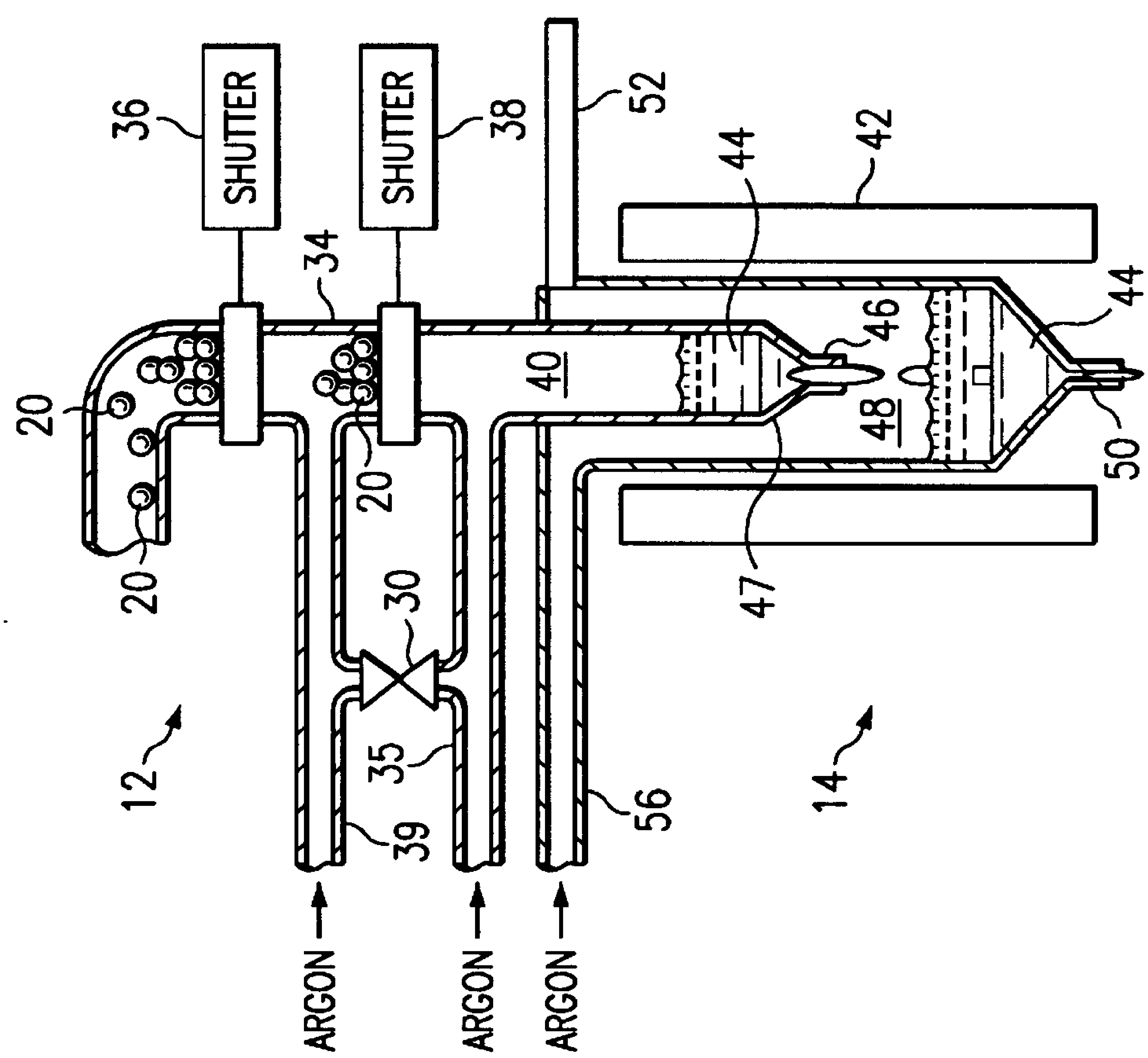
ARGON

Fig. 4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ARGON

Fig. 3

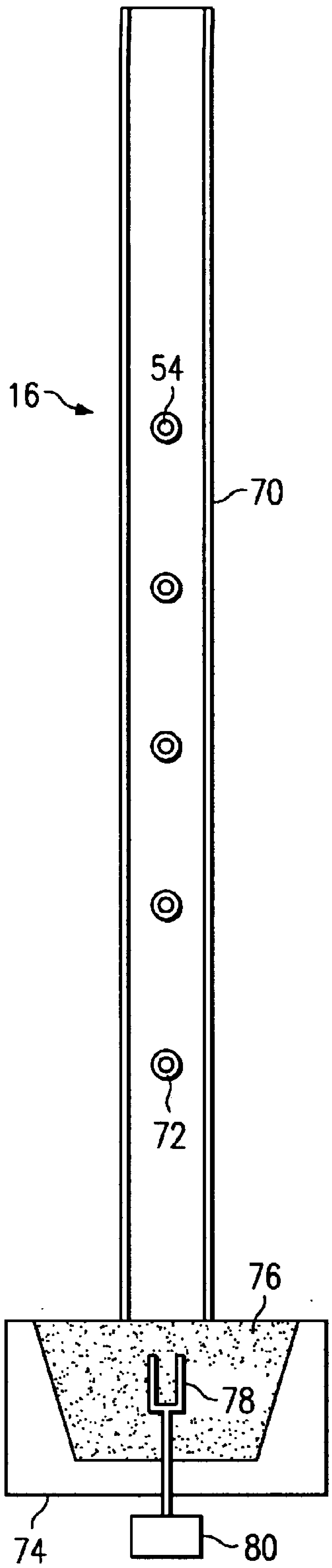

Fig. 5

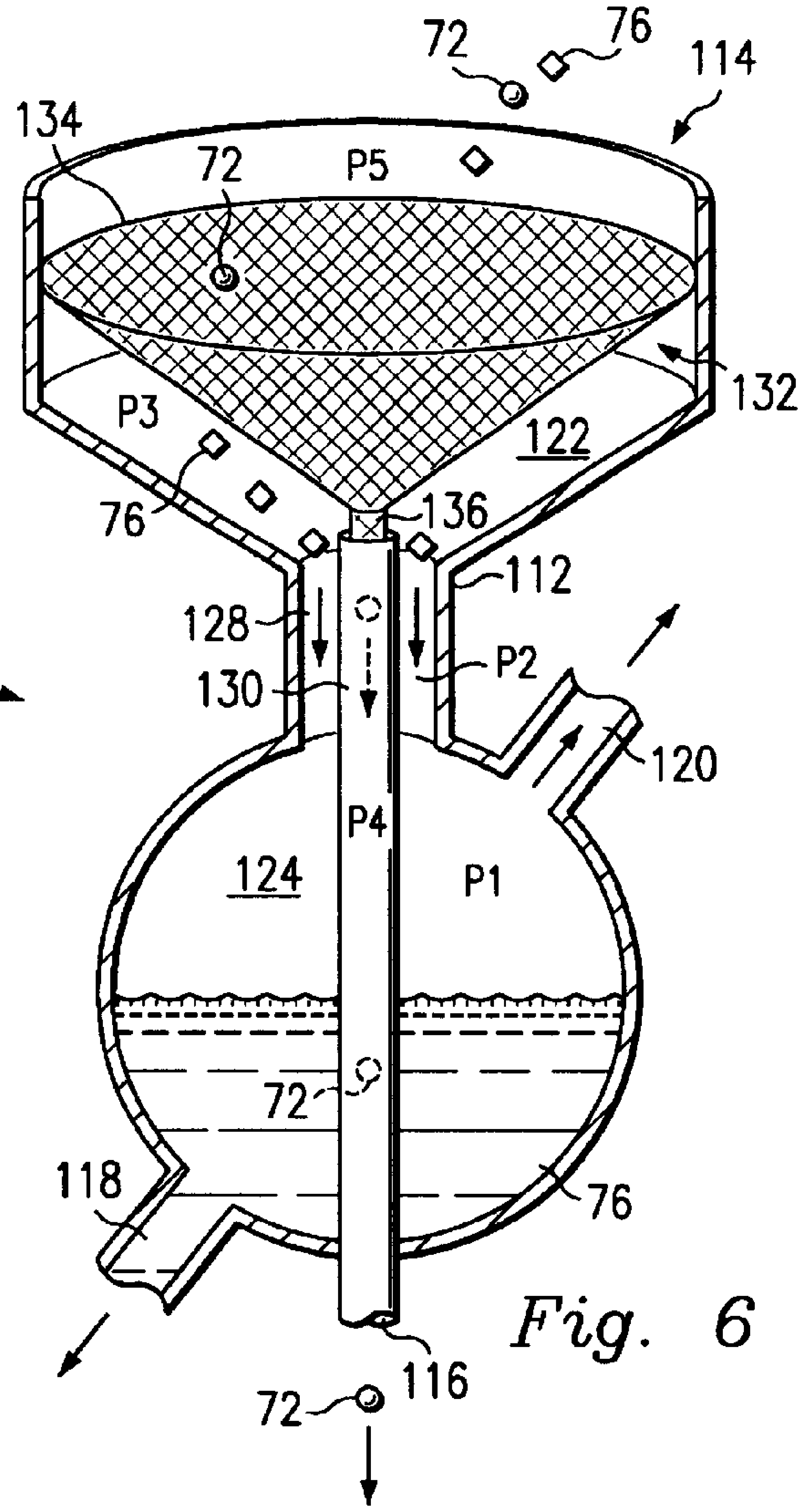

Fig. 6

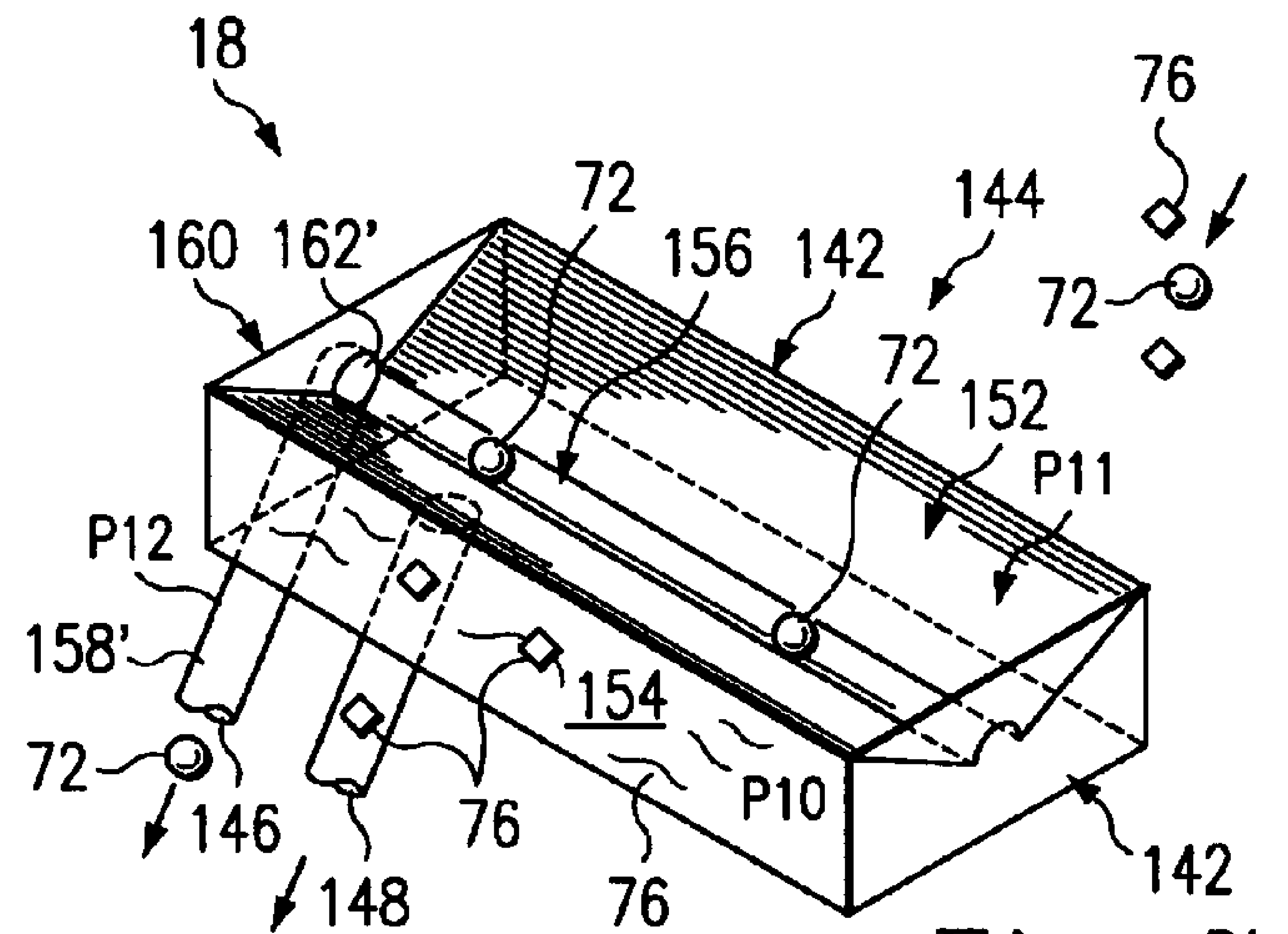

Fig. 7

JET SYSTEM FOR SPHERICAL SHAPE DEVICES

This disclosure claims the benefit of U.S. Ser. No. 60/279,484, filed Mar. 28, 2001.

BACKGROUND

The invention relates generally to semiconductor devices, and more particularly, to a system and method for creating three-dimensional semiconductor devices.

In U.S. Pat. No. 5,955,776, which is hereby incorporated by reference, a method and apparatus for manufacturing spherical-shaped semiconductor integrated circuit devices is disclosed. Although certain systems and methods for performing various processing operations are discussed in the above-referenced patent, it is desired to further improve on the operations. For example, in making a p-n junction diode, a first type (e.g. n-type) outer layer is diffused onto a second type (e.g., p-type) spherical shaped semiconductor substrate. It is desired that both the outer layer and the inner substrate are maintained at an appropriate shape, thickness, and diffusion concentration.

In U.S. patent Ser. No. 09/490,650, now U.S. Pat. No. 6,365,493, and Ser. No. 09/489,782, now U.S. Pat. No. 6,331,477 which are hereby incorporated by reference, methods for doping material on a spherical shaped substrate in a non-contact environment are disclosed. These methods can be used to make spherical p-n junction diodes for solar cell applications. It is desired, however, to make uniform sized spherical p-n diodes in a continuous operation (e.g., a single step).

In U.S. patent Ser. No. 09/363,420, now U.S. Pat. No. 6,264,742, and Ser. No. 09/672,566, now U.S. Pat. No. 6,383,287, which are hereby incorporated by reference, methods for making single crystal devices and for making uniformly thick p-n junctions on these devices are disclosed, respectively. It is desired, however, to better automate the production of these devices in a highly manufacturable setting.

SUMMARY

A technical advance is achieved by a new and improved jet system for making spherical shaped devices. In one embodiment, the system includes a supply system for providing predetermined amounts of raw material at a temperature at or above a melting point of the material, and for moving the predetermined amounts of melted raw material without physical contact so that a liquid surface tension of each predetermined amount of melted raw material will cause the material to form into a spherical shape device. The system also includes a container of powder in which the solidified spherical shaped devices are received from the supply system and means for separating the powder from the solidified spherical shaped devices after the devices have been received.

In another embodiment, the system includes a supply system for providing predetermined amounts of raw material into a chamber, which is used for melting the raw material. The melted raw material is then provided to a dropper for measuring predetermined amounts of the melted raw material (droplets) and releasing the droplets into a drop tube, where they are cooled and solidified into spherical shaped silicon devices. The system includes a container of silicon powder in which the solidified spherical shaped devices are received from the drop tube, the container including a stirring mechanism for agitating the silicon powder. The system also includes a separating device for separating the powder from the solidified spherical shaped devices after the devices have been received into the container.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a flow chart of a new and improved processing flow for creating spherical shaped devices according to one embodiment of the present invention.

FIG. **2** is a diagram of a feeder device, such as can be used in the processing flow of FIG. **1**.

FIGS. **3–4** are diagrams of a dropper device, such as can be used in the processing flow of FIG. **1**.

FIG. **5** is a diagram of a receiver device, such as can be used in the processing flow of FIG. **1**.

FIGS. **6–7** are diagrams of a separator device, such as can be used in the processing flow of FIG. **1**.

DETAILED DESCRIPTION

The present disclosure provides many different embodiments, or examples, for implementing different features of the invention. Specific examples of components, sizes, and arrangements are described below to simplify the present disclosure and are not intended to limit the invention.

Referring to FIG. **1**, the reference numeral **10** designates, in general, one embodiment of a processing flow for making spherical shaped semiconductor devices. The processing flow **10** utilizes a feeder system **12** that provides continuous feeding of raw material and prevents undesired material and/or fluids from entering other components. The feeder system **12** provides the material to a dropper **14**, which is used to make the spherical shaped semiconductor devices. The spherical shaped semiconductor devices are received into a receiver **16**, which include a soft powderlike refractory receiving material, such as quartz. The devices and receiving material are then provided to a separator **18** where the receiving material is separated and recycled.

The following discussion provides many different embodiments for different systems that can be used in the processing flow **10**. Each of the embodiments are different, but may include similar components that are similarly numbered.

Referring now to FIG. **2**, in one embodiment of the feeder system **12**, raw material Si **20** is received in the form of chunks, powder or granules into a receiver **22**. The receiver **22** includes a sensor **24** for detecting the raw material and ensuring a continuous feeding of raw material into the feeder. The flow of the raw material **20** is controlled by two valves **26**, **28**. In addition, an argon gas is controlled by valves **28** and **30**.

The feeder **12** is designed to ensure continuous feeding of the raw material **20** into the dropper system **14**, while at the system eliminating ingress of atmosphere into a nozzle (FIG. **3**) of the dropper. When the first valve **26** is opened, the raw material **20** will drop into a first tube portion **34**. Thereafter, the first valve **26** is closed and the third valve **30** is opened to introduce Argon through a first pipe **35**. When the second valve **28** is opened the feed will be dropped into the nozzle. The second valve **28** and the third valve **30** are thereafter closed. In one embodiment, the dropper **14** is as disclosed in presently incorporated U.S. patent Ser. No. 09/672,566.

Referring now to FIGS. **3** and **4**, in other embodiments of the feeder system **12**, the flow of the raw material **20** is controlled by two shutters **36**, **38**. In the embodiment of FIG. **3**, a second Argon pipe **39** is also used to introduce Argon to the operation.

The feeder system **12** provides the raw material **20** to the receiver system **14**, where it proceeds to a chamber **40**. The raw material is melted by a furnace **42** into a liquid state (designated as liquid material **44**), which in the case of pure silicon is near 1400° C. In some embodiments, such as is shown in FIG. **4**, the chamber **40** is attached to a first vibration device **46**, such as a piezo-electric vibrator (PZT). The first PZT **46** encourages the liquid material **44** to move through a first nozzle **47** at a predetermined rate into a second chamber **48**. In addition, a gas (e.g., Argon) may be supplied through a first pipe **35** to apply a pressure to the first chamber **40** and further help control the flow of the liquid material into the second chamber **48**.

The second chamber **48** receives the liquid material **44** from the first chamber **40** and feeds it into a jet nozzle **50**, that is controlled by a second vibration device **52**. The nozzle **50** and second vibration device **52** can thereby produce liquid droplets **54** of a predetermined size, e.g. about one millimeter. In addition, a gas (e.g., Argon) may be supplied through a second pipe **56** to apply a pressure to the second chamber **48** and further help control the creation of the liquid droplets **54**.

Referring now to FIG. **5**, in one embodiment of the receiver **16**, the liquid droplets **54** can fall, without contact, through a drop tube **70**. The rate at which the droplets move can be controlled, such as through a pressure or a moving fluid through the drop tube **70**. Eventually, the droplets solidify into spheres **72**. The temperature of the spheres **72** is relatively high, such as between 1000°–1300° C. (near the melting point of silicon).

The solidified spheres **72** are then received into a container **74**. In the present embodiment, the container **74** is a furnace. The furnace **74** includes a powdered refractory material (e.g., quartz powder, silica, or ceramic powder) **76**, which is heated to about 1000°–1300° C. The powder **76** is continually stirred by a quartz mixing rod **78** connected to a motor **80**. The stirring exposes fresh powder **76** to the falling spheres **72**. The powder **76** thereby provides a soft landing for the spheres **72**.

Referring again to FIG. **1**, the separator **18** receives the spheres **72** and powder **76** from the furnace. It is understood that there may be one or more separators **18** to repeatedly separate the powder **76** from the spheres **72**. The spheres **72** can be provided to other downstream processing operations and the powder **76** can be returned to the receiver **16**.

Referring now to FIG. **6**, in one embodiment the separator **18** includes an enclosure **112** having an inlet opening **114** and three outlet openings **116, 118, 120**. The outlet opening **116** is located diametrically opposite the inlet opening **114**. The enclosure **112** defines two chambers **122, 124**. The chamber **122** is a separation chamber for receiving a supply of spheres **72** and powder **76** and the chamber **124** is a reservoir for receiving, storing and expelling the separated powder **76** through the outlet **118**. The chamber **122** and reservoir **124** are connected by a neck portion **128**.

A vertically extending conduit **130** is coaxially aligned with the chamber **122**, the reservoir **124** and the neck **126**. The conduit **130** supplies a path between the outlet **116** and a separating device **132** located in the separation chamber **122**. For the present embodiment, the separating device **132** is a wire mesh formed into a funnel shape. The wire mesh **132** includes a plurality of openings having a diameter less than one-half the diameter of the sphere **72**. The wire mesh **132** includes an opening **134** that registers with the inlet opening **114** to receive the supply of spheres **72** and powder **76**. The wire mesh **132** also includes an outlet **136** that registers with the conduit **130**.

Although not shown, a vacuum source is connected to the outlet **120** for providing a negative pressure inside the reservoir **124**, the neck **128**, and the separation chamber **122**. The negative pressure is not strong enough to lift either the spheres **72** or the powder **76**.

For the sake of reference, the pressure at several locations inside the fluid separating processor **18** are identified. A pressure P1 represents the pressure inside the reservoir **124**; a pressure P2 represents the pressure inside the neck **128**; a pressure P3 represents the pressure inside the separation chamber **122**; a pressure P4 represents the pressure at the conduit **130**; and a pressure P5 represents the pressure at the opening **114**. The following comparative relationships exist between the different pressures P:

$$P1 < P2 \tag{1}$$

$$P2 < P3 \text{ and } P5 \tag{2}$$

$$P4 > P3 \text{ and } P5 \tag{3}$$

In operation, the supply of spheres **72** and powder **76** are introduced into the opening **114**. The spheres **72** are preferably of a generally spherical shape and could be of the same type formed according to the technique disclosed in the above-identified and presently incorporated patent application Ser. No. 08/858,004. The powder **76** may be a flow of constituents or liquids or the like. For the sake of example, the powder **76** is a high-viscosity liquid from a previous process.

When the spheres **72** and powder **76** enter the separation chamber **122**, they contact the wire mesh **134** and are propelled towards the opening **136**. In the preferred embodiment, the pressure P3 assists this propelling action, but in other embodiments, the momentum of the spheres **72** and powder **76**, or other forces, may so assist.

As the powder **76** is propelled towards the opening **136**, it flows through the wire mesh **134**. The pressure P3 helps to draw the powder **76** through the wire mesh **134**. In some embodiments, the (higher) pressure P4 from the conduit **130** also persuades the powder **76** to move through the wire mesh **134**. In so doing, even highly viscous fluid will be drawn through the wire mesh, despite the wire mesh's narrow openings. The fluid is then drawn by either gravity or by the pressure P2, or both, into the neck **128** and further drawn (by gravity and/or the pressure P1) into the reservoir **124**. It is noted that the reservoir **124** is physically isolated from the interior of the conduit **130** so that none of the powder **76** can enter the conduit. The reservoir **124** maintains a portion of the powder **76** while draining out another portion through the outlet **118**.

As the spheres **72** move toward the opening **136**, they cannot move through the wire mesh **134**. Instead, the spheres **72** move into the conduit **130** and then exit through the outlet **116**.

Referring to FIG. **7**, in another embodiment, the separator **18** includes an enclosure **142** having an inlet opening **144** and two outlet openings **146, 148**. The outlet opening **146** is opposite the inlet opening **144**. The enclosure **142** defines a chamber **152** and a reservoir **154**. The chamber **152** is a separation chamber for receiving a supply of spheres **72** and powder **76** and the reservoir **154** receives and stores and expels the separated powder **76** using the outlet **148**. The chamber **152** and reservoir **154** are connected by a slot **156**.

A vertically extending conduit **158** is connected at one end **160** of the chamber **152** and passes through the reservoir **154**. The conduit **158** supplies a path between the outlet **146** and an opening **162** at the end **160** of the slot **156**. For the present embodiment, the slot **156** acts as a separation device by providing an opening with a diameter less than the diameter of the sphere **72** (except at the opening **162**) but sufficiently large to allow the powder **76** to flow there through.

Although not shown, a vacuum source is connected to the outlet **148** for providing a negative pressure inside the reservoir **154**, the slot **156**, and the separation chamber **152**. Also not shown, a plurality of air inlets may be provided in the chamber **152**. The air inlets may be used to provide a dry, inert gas such as N2 to the chamber.

For the sake of reference, the pressure at several locations inside the fluid separating processor **18** are identified. A pressure **P10** represents the pressure inside the reservoir **154**; a pressure **P11** represents the pressure the separation chamber **152**; and a pressure **P12** represents the pressure at the conduit **158**. The following comparative relationships exist between the different pressures P:

$$P10<P11 \text{ and } P12 \tag{4}$$

In operation, the supply of spheres **72** and powder **76** are introduced into the opening **144**, opposite to the end **160**. When the spheres **72** and powder **76** enter the separation chamber **152**, they contact the slot **156** and are propelled towards the opening **162** at the end **160**.

The slot **156** is small enough so that a sphere **72** cannot fall into the reservoir **154**, but the powder **76** can. The pressure **P10** and the dry inert air help to draw the powder **76** through the slot **156**. In some embodiments, the pressure **P12** from the conduit **130** may be high to prevent any of the powder **76** from entering the conduit.

It is noted that the reservoir **154** is physically isolated from the interior of the conduit **158** so that none of the powder **76** can enter the conduit. The reservoir **154** drains the powder **76** through the outlet **148**.

It is understood that several variations may be made in the foregoing. For example, different heating steps may be used in different parts of the system **10**. Other modifications, changes and substitutions are also intended in the foregoing disclosure and in some instances some features of the invention will be employed without a corresponding use of other features. Accordingly, it is appropriate that the invention be construed broadly.

What is claimed is:

1. A system for making spherical shaped devices, comprising:

a supply system for providing predetermined amounts of raw material at a temperature at or above a melting point of the material, and for moving the predetermined amounts of melted raw material without physical contact so that a liquid surface tension of each predetermined amount of melted raw material will cause the material to solidify into a spherical shape device;

a container of powder in which the solidified spherical shaped devices are received from the supply system; and

means for separating the powder from the solidified spherical shaped devices after the devices have been received.

2. The system of claim **1** wherein the supply system includes:

a first chamber for containing the raw material in a liquid state; and

a first dropper registering with the first chamber for forming the predetermined amounts of melted raw material.

3. The system of claim **2** wherein the supply system further includes:

an inlet for receiving a gas to facilitate the formation of the predetermined amounts of melted raw material by the first dropper.

4. The system of claim **2** wherein the supply system further includes:

a vibrator connected to the first dropper to facilitate the formation of the predetermined amounts of melted raw material by the first dropper.

5. The system of claim **2** wherein the supply system includes:

a second chamber for containing the raw material in a liquid state; and

a second dropper registering with the first chamber for providing the melted raw material to the first chamber and maintaining a relatively constant supply of the melted raw material in the first chamber.

6. The system of claim **1** wherein the container includes:

means for agitating the powder in which the solidified spherical shaped devices are received and moving the powder and devices towards the separation means.

7. The system of claim **1** wherein the separator includes:

an enclosure including an input for receiving the receiver material and the devices, a first outlet for outputting the devices and a second outlet for outputting the receiver material;

first and second chambers defined within the enclosure, the first chamber registering with the input and the first outlet and the second chamber registering with the second outlet;

a separator device positioned between the first and second chambers, the separator device having at least one opening having a size that is less than a size of the device but greater than a size of the receiver material; and

means for providing a negative pressure to the second chamber to encourage the receiver material to flow from the first chamber, through the at least one opening, and into the second chamber.

8. The system of claim **1** wherein the separator includes a wire mesh.

9. The system of claim **8** wherein the wire mesh includes a plurality of openings with a size less than one half the size of the device but greater than the size of the receiver material.

10. The system of claim **7** wherein the separator further includes:

a third outlet for registering the pressure means with the second chamber.

11. The system of claim **7** wherein the first outlet has a positive pressure, as compared to the negative pressure of the second chamber.

12. The system of claim **7** wherein the second chamber facilitates returning the separated receiver material back to the container.

13. A method for making spherical shaped semiconductor devices from molten raw material, the method comprising:

dropping predetermined amounts of the molten raw silicon material into a drop tube;

solidifying the predetermined amounts inside the drop tube so that a liquid surface tension of each predetermined amount will cause the material to form a spherical shape device; and

receiving the solidified spherical devices into a container of silicon powder.

14. The method of claim **13** further comprising:

separating the powder from the solidified spherical shaped devices after the devices have been received.

15. The method of claim **13** further comprising:

forming the predetermined amounts of melted raw material using a pressurized gas and a dropper.

16. The method of claim **13** further comprising:

forming the predetermined amounts using a vibrator connected to a dropper.

17. The method of claim **13** further comprising:

agitating the powder in which the solidified spherical shaped devices are received.

18. The method of claim **13** further comprising:

stirring the powder in which the solidified spherical shaped devices are received.

19. A system for making spherical shaped silicon devices, comprising:

a supply system for providing predetermined amounts of raw material into a chamber;

the chamber for melting the raw material;

a dropper for measuring predetermined amounts of melted raw material (droplets) and releasing the droplets into a drop tube;

the drop tube for receiving the droplets and cooling the droplets into solidified spherical shaped silicon devices;

a container of silicon powder in which the solidified spherical shaped devices are received from the drop tube, the container including a stirring mechanism for agitating the silicon powder; and

a separating device for separating the powder from the solidified spherical shaped devices after the devices have been received into the container.

20. The system of claim **19** wherein the stirring mechanism of the container also services to move the received spherical shaped devices and a portion of the silicon powder towards the separating device.

* * * * *